Background analysis of CEPC vertex detector

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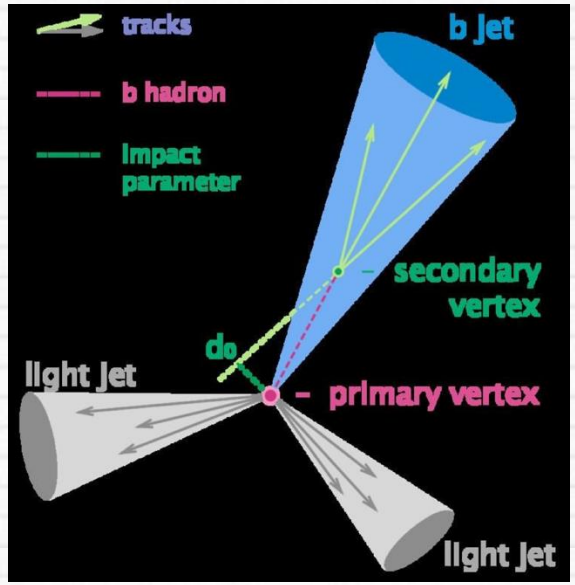
Intro: CEPC VXD

High-precision vertex detectors are crucial for the realization of the CEPC physics goals

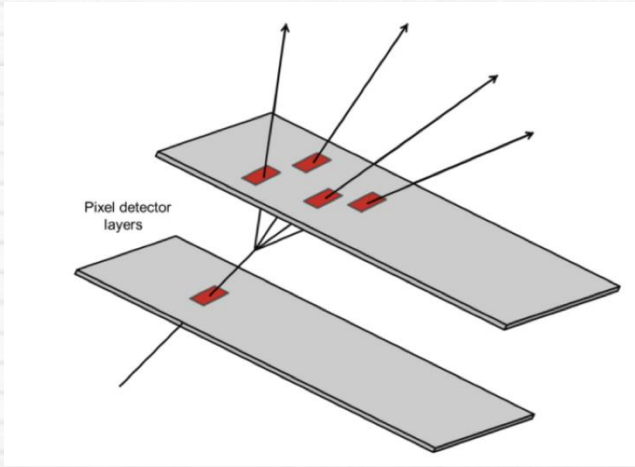
- Flavor physics (a large number of b/c quark jets, τ leptons)
- Higgs physics ($H \to bb/cc/gg$ and $H \to \tau\,\tau$)



Goal: σ(IP) ~5μm for high P track

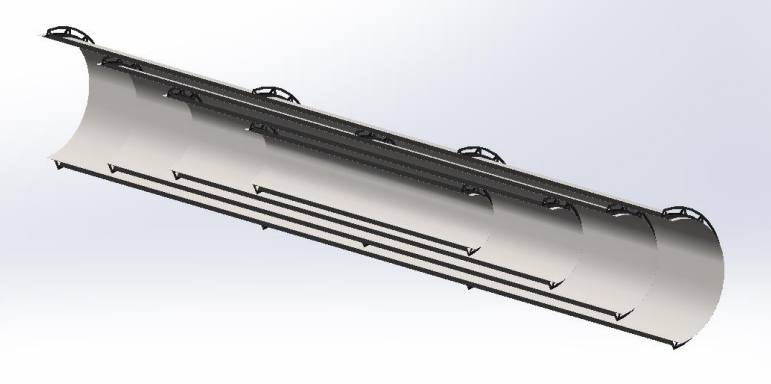
CDR design specifications

- Single point resolution ~ 3μm
- Low material (0.15% X_0/Layer)
- Low power (< 50mW/cm^2)
- Radiation hard (1 Mrad/year)

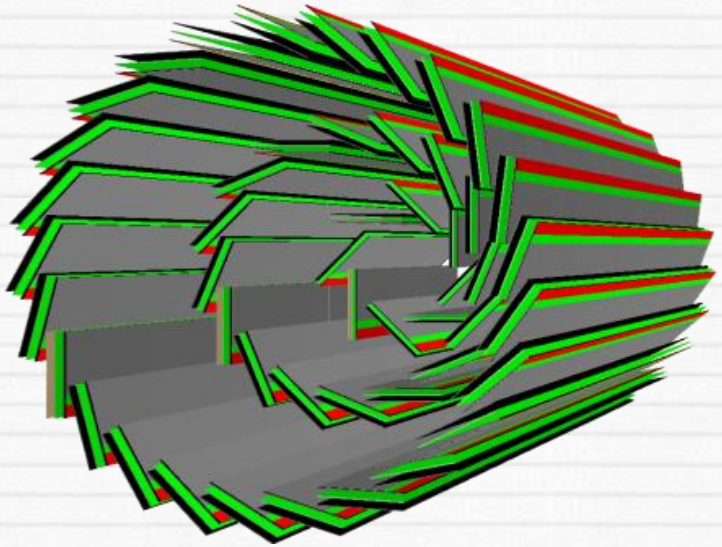


Intro: CEPC VXD

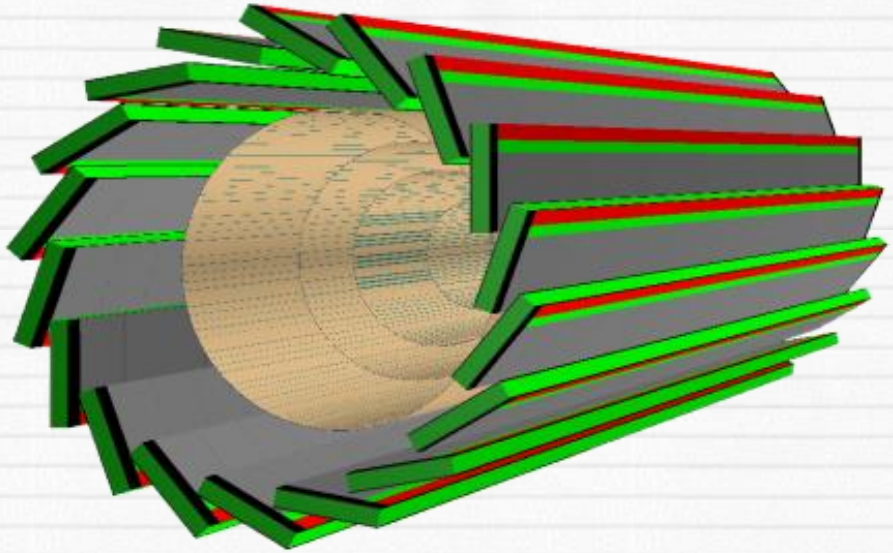
To meet the design specifications and enhance performance, VXD has undergone multiple iterations in various aspects such as geometric structure.



Stitching

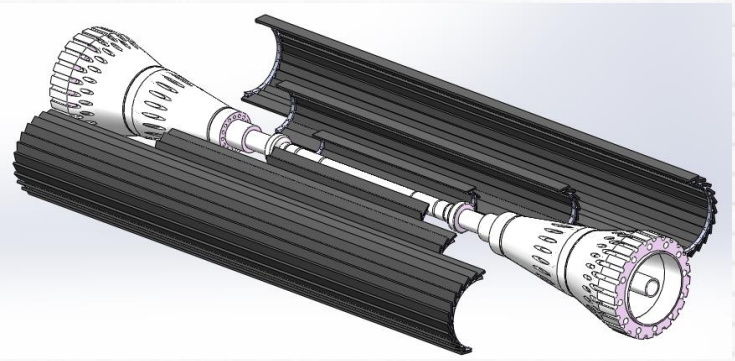


Staggered Ladder



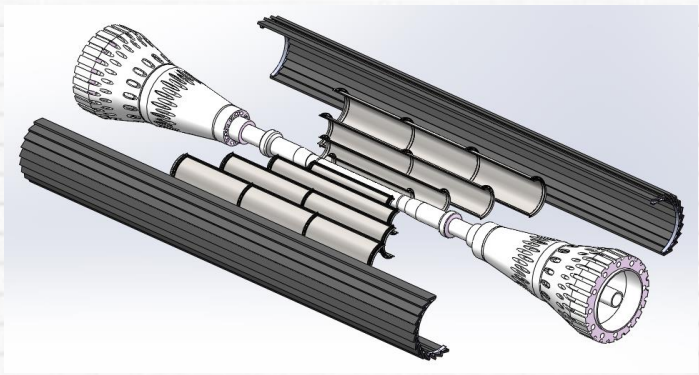
Composite(Ladder + Stitching)

Intro: VXD Geo



Staggered Ladder

- Series of modules
- Two layers attached together
- Nearly cylindrical



Composite(Ladder + Stitching)

- Each layer is relatively scattered
- Cylindrical

Geometry during data generation

↕ Slight differences

Newest geometry

These differences have minimal impact on the results

Layer	Radius(OldGeo)/mm	Radius(NewGeo)/mm
1	11.39	12.20; 12.70
2	13.53	19.20; 19.70
3	26.63	25.90; 26.40
4	29.67	32.90; 33.40
5	43.51	44.10
6	47.15	47.74

Result: Higgs HitRate NewGeo

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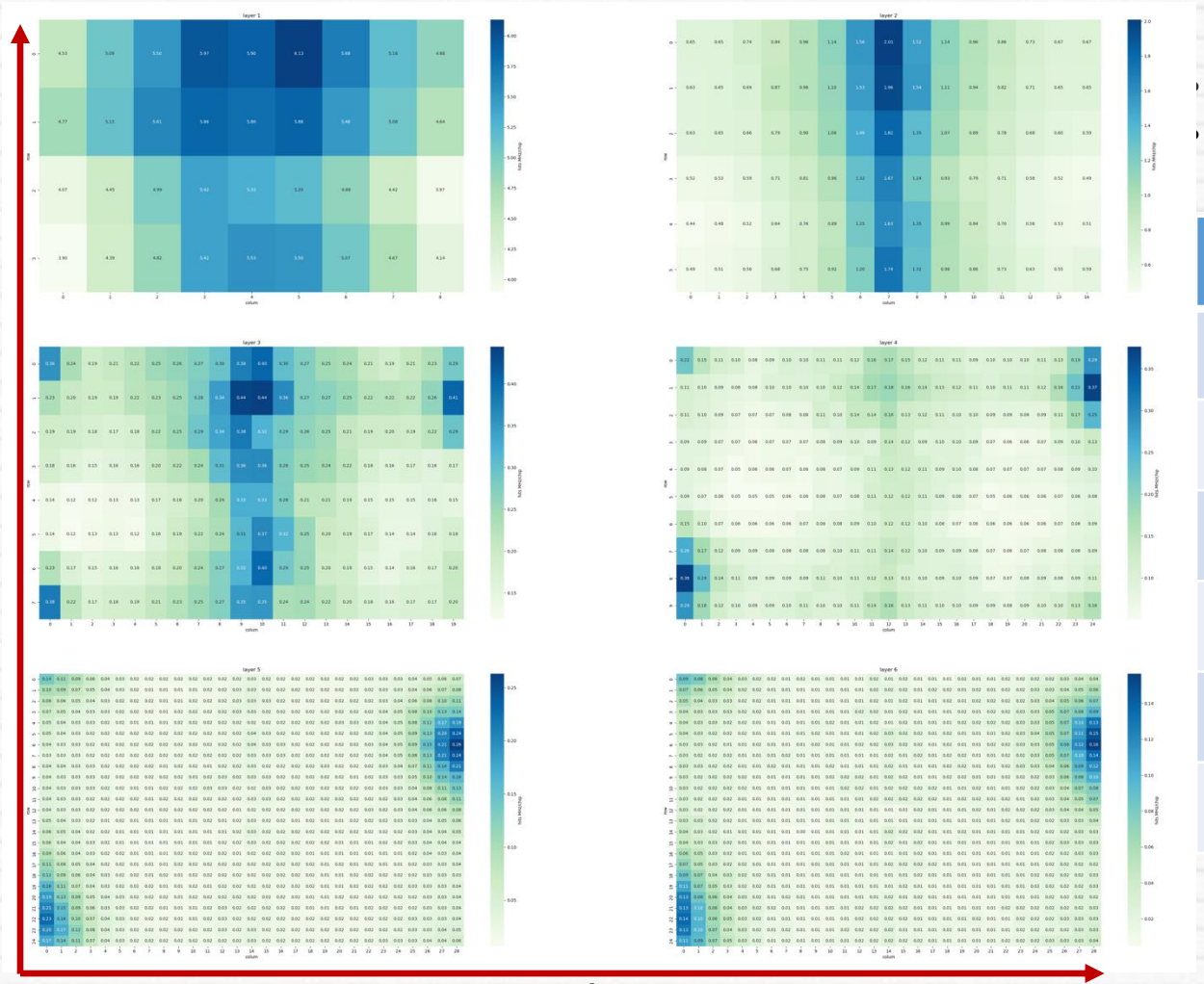
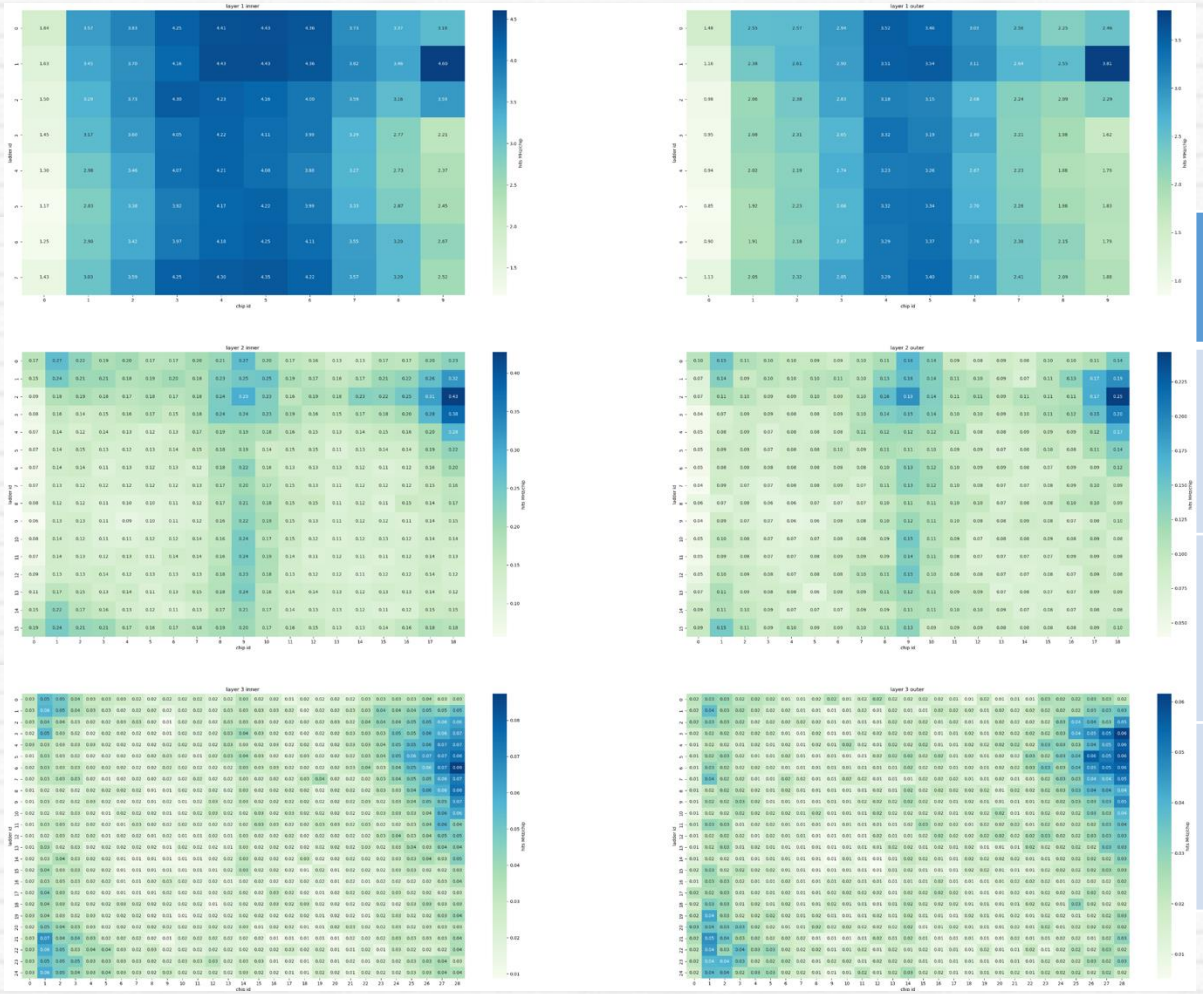


Total entries: 2611449 (2000Evt*10BX*355ns)@(53%Gap)
Max hit rate: 2.451 MHz/sensor

Layer	A hit rate MHz/sensor	M hit rate MHz/sensor	A hit density MHz/cm2	M hit density MHz/cm2
1	1.983	2.451	0.496	0.613
2	0.378	0.842	0.090	0.200
3	0.098	0.196	0.023	0.047
4	0.044	0.153	0.010	0.035
5	0.015	0.108	0.004	0.033
6	0.010	0.070	0.003	0.021

A for average, M for maximum.

Result: Higgs HitRate OldGeo



- Total entries: 4120583 (2000Evt*10BX*355ns)@(53%Gap)
- Max hit rate: 2.164 MHz/sensor

Layer	Inner/outer	A hit rate MHz/sensor	M hit rate MHz/sensor	A hit density MHz/cm2	M hit density MHz/cm2
1	i	1.622	2.164	0.495	0.660
	o	1.150	1.790	0.351	0.546
2	i	0.074	0.201	0.022	0.061
	o	0.044	0.116	0.014	0.035
3	i	0.012	0.041	0.004	0.013
	o	0.009	0.029	0.003	0.009

A for average, M for maximum, and i for inner, o for outer.

Result: OldGeo vs. NewGeo

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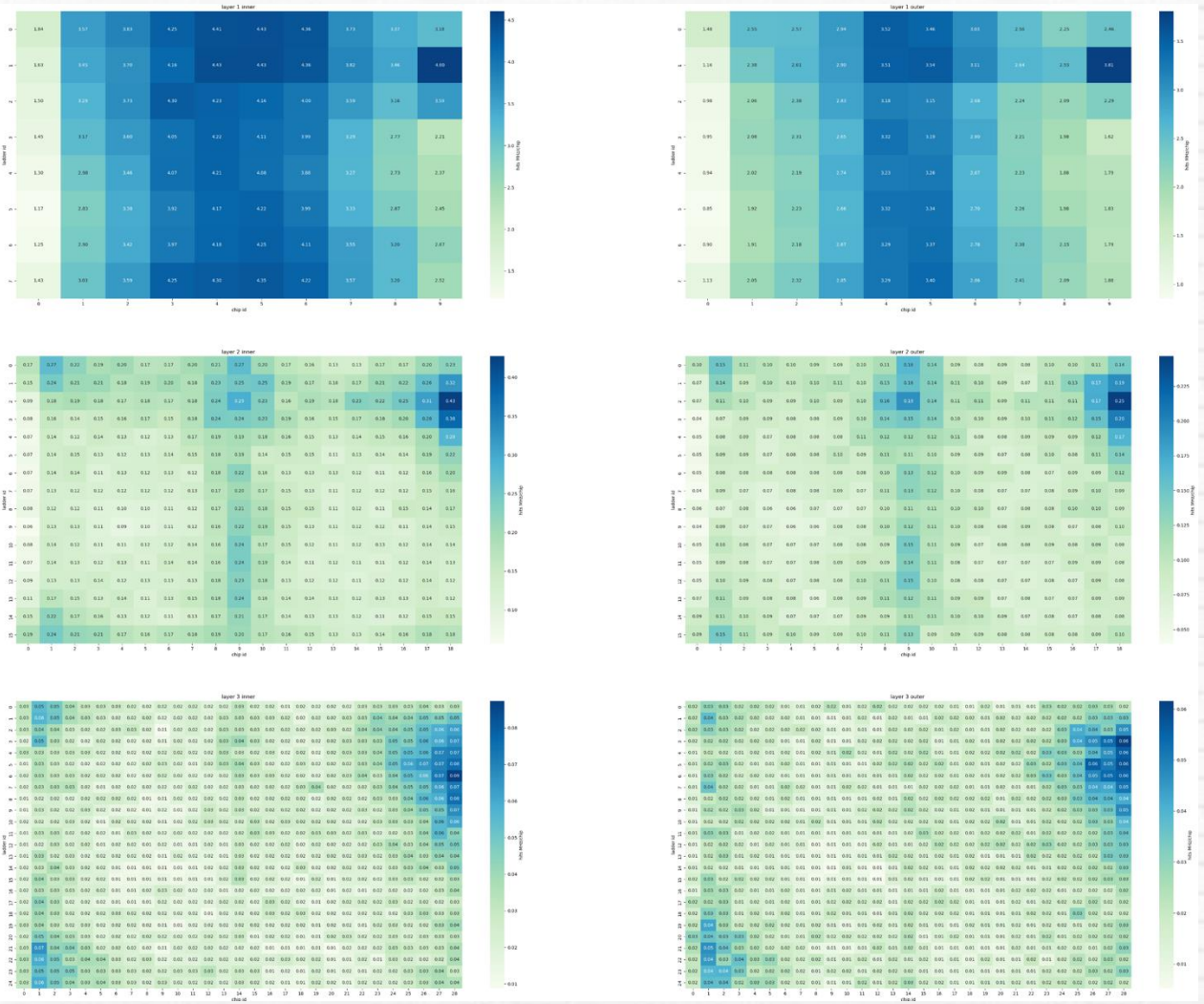
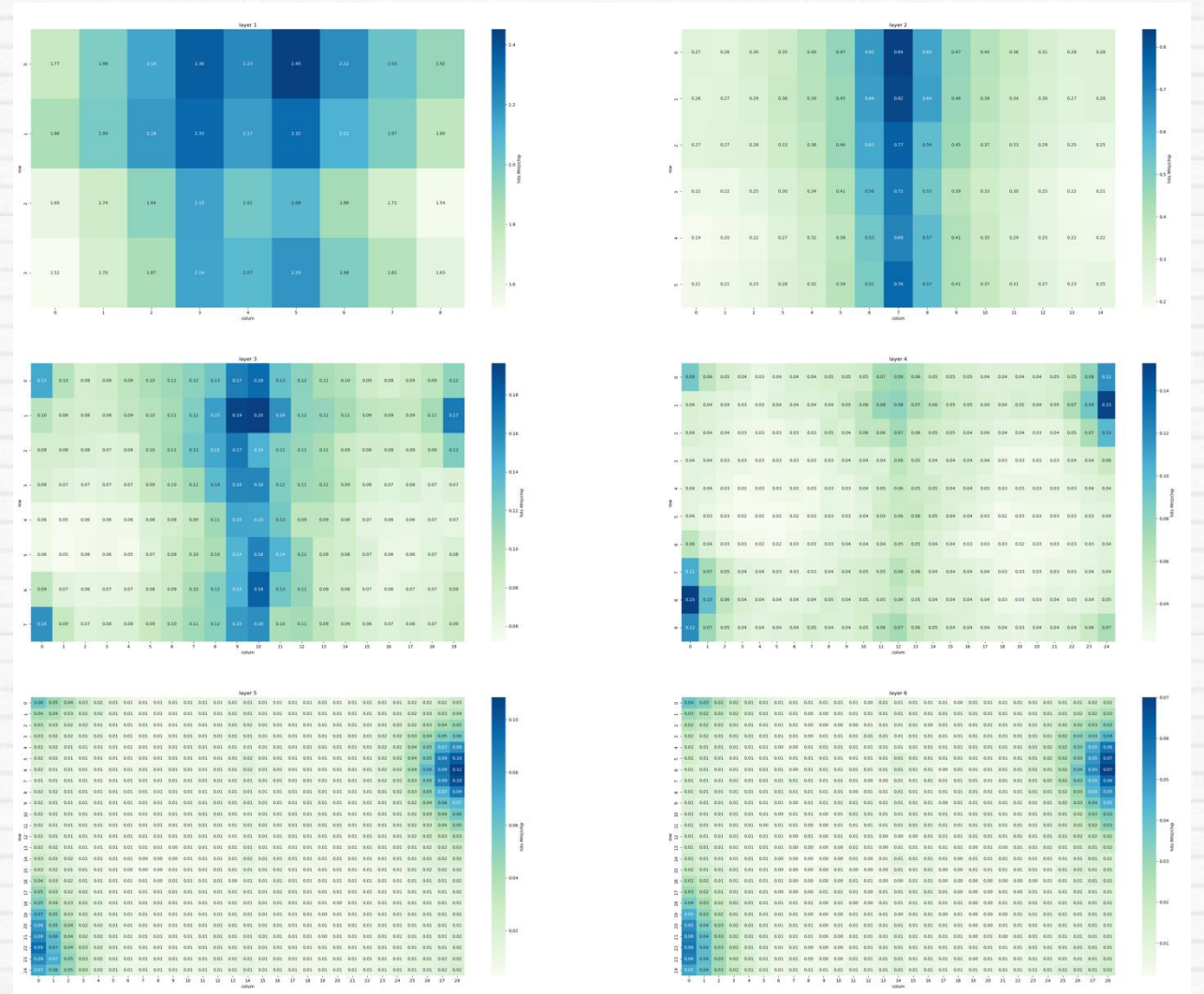
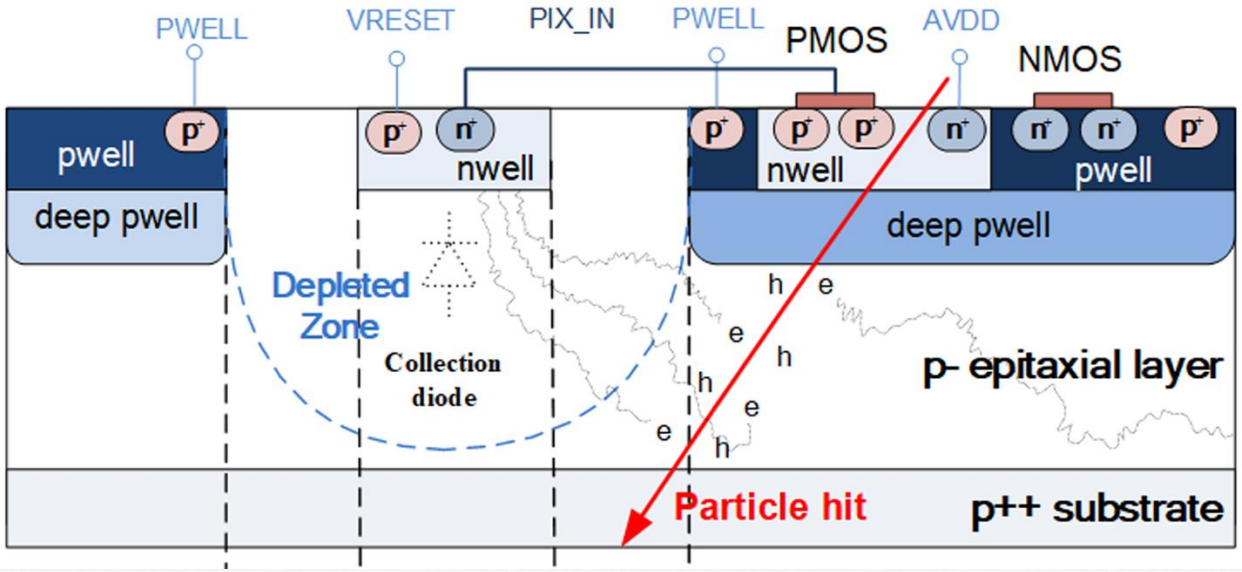




Old Geo: Staggered Ladder

New Geo: Composite(Ladder + Stitching)

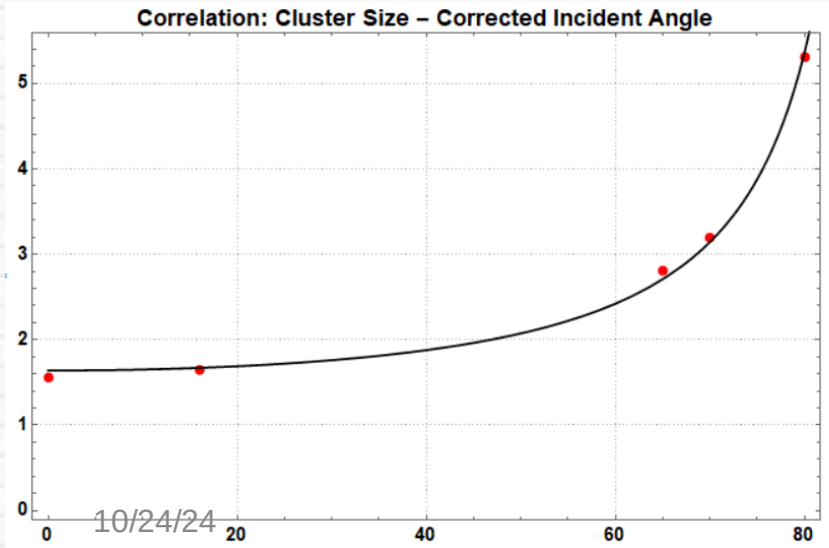
Cluster Size



- Cluster Size should be approximately proportional to the track length.
- The sensor is of uniform thickness
- Sensor can be regarded as planar on the order of a few pixels

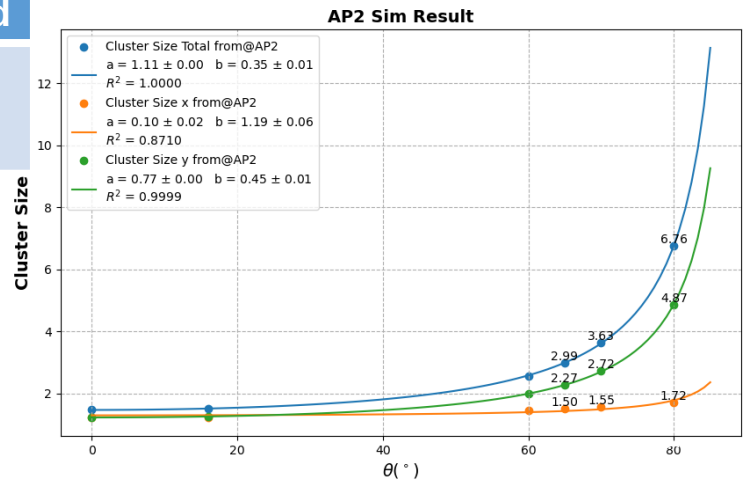
$$C = a \sec\theta + b$$

C is the Cluster Size, and θ is the incident angle

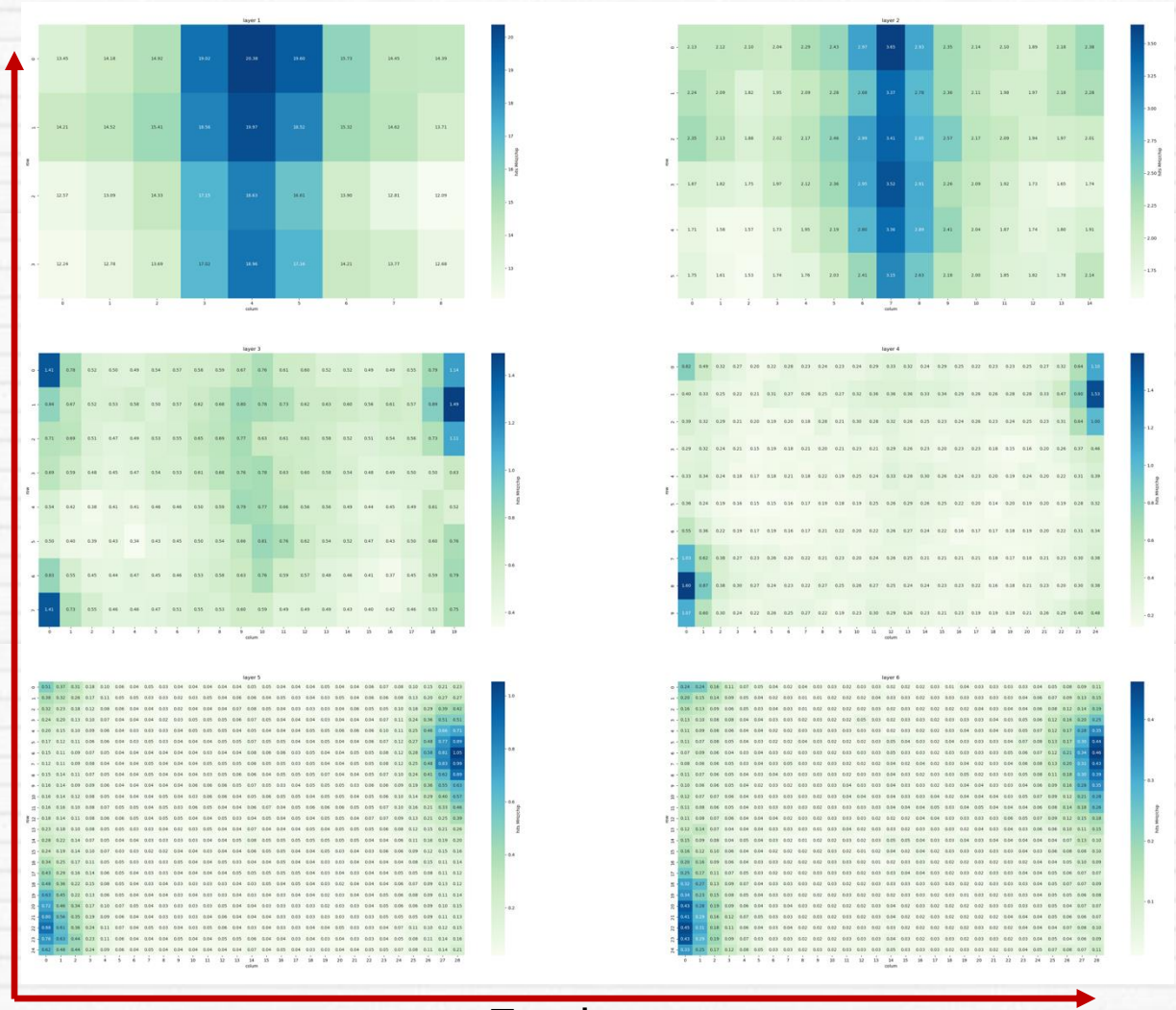


Param	Estimate	Std Error	RSquared
a	0.783	0.022	0.9995
b	0.856	0.069	

The model is reasonbale



Result: Higgs DataRate NewGeo



Take 32 bit / PixelSignal:

Vaild	Ts_chip	Column	Row	Pattern	Total
1 bit	8 bit	9 bit	10 bit	4 bit	32 bit

Layer	A Data rate Mbps/sensor	M Data rate Mbps/sensor	A Data rate Mbps/cm2	M Data rate Mbps/cm2
1	493.018	652.018	123.255	163.004
2	70.927	116.668	16.887	27.778
3	18.845	47.790	4.487	11.379
4	9.144	51.128	2.078	11.620
5	3.363	33.700	1.026	10.284
6	1.920	14.796	0.586	4.515

A for average, M for maximum.

Result: HitRate vs. DataRate

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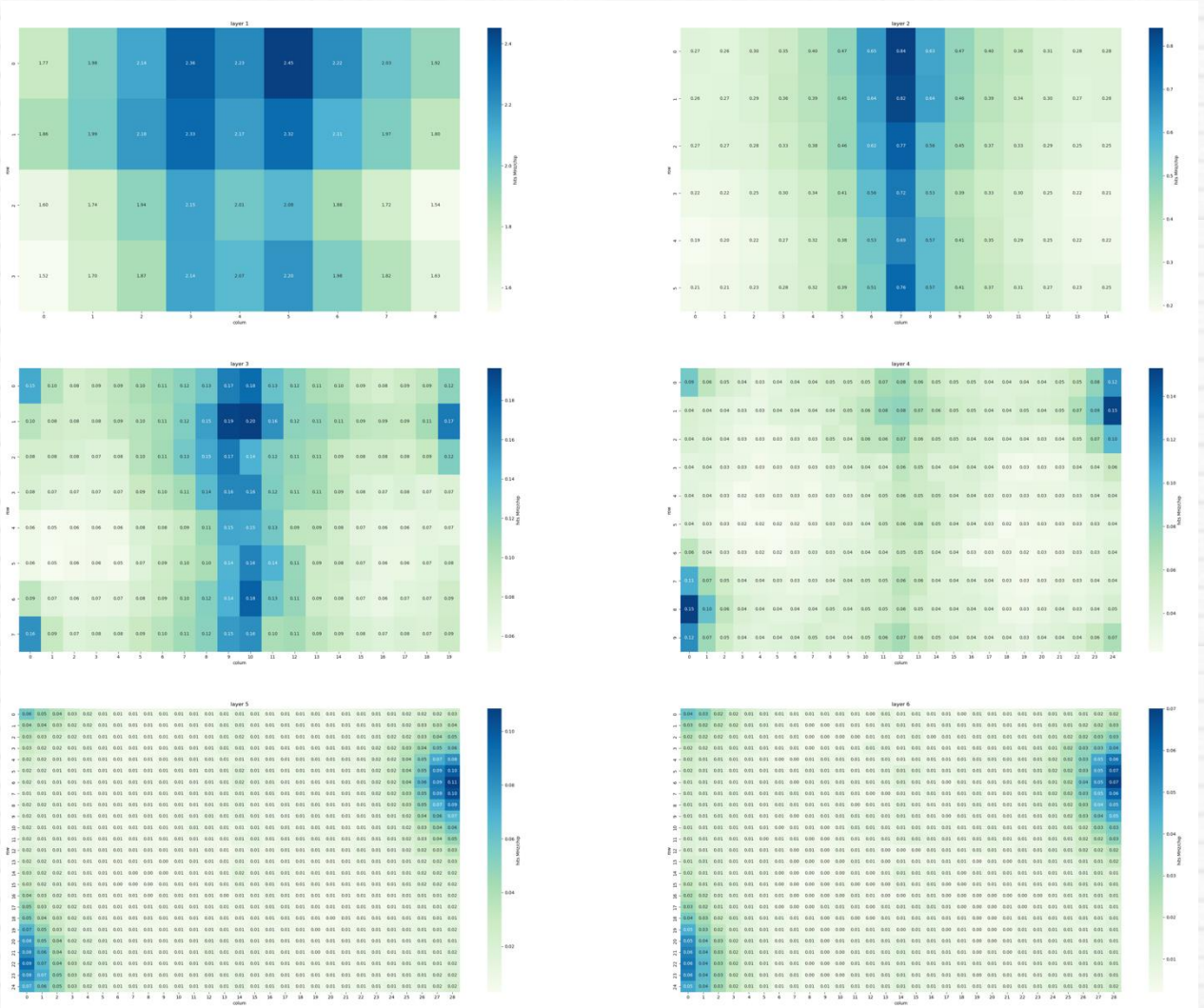
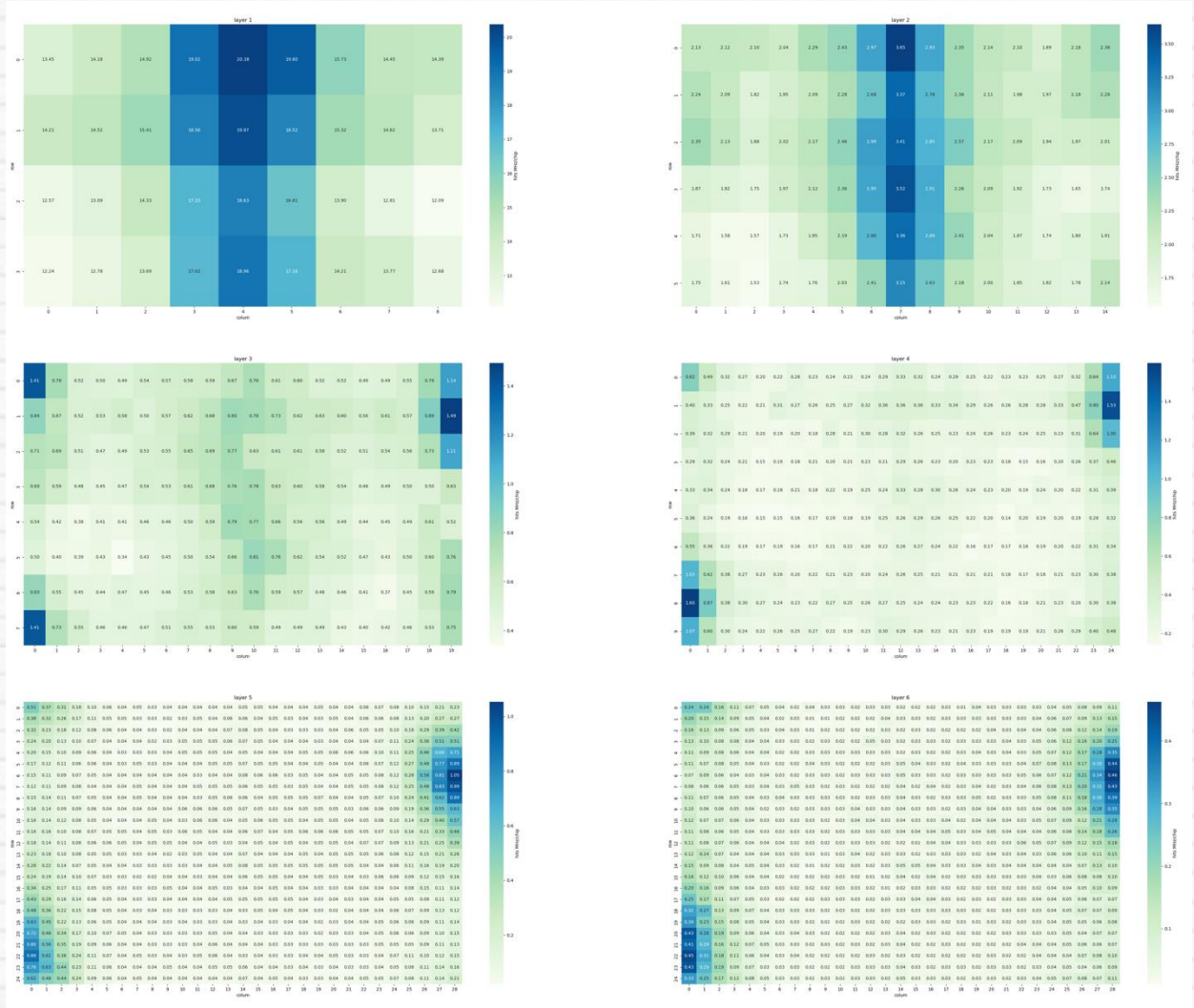




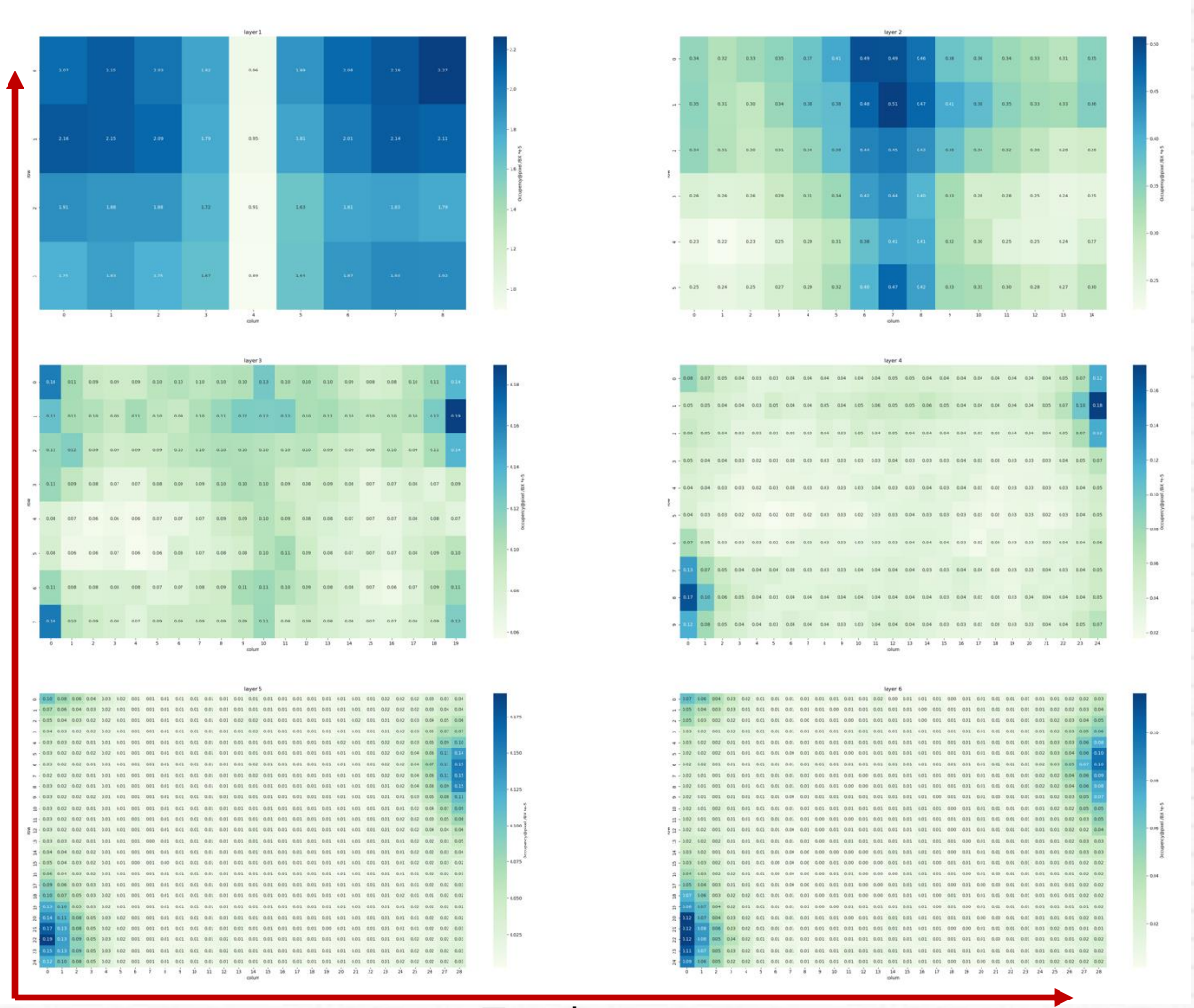
Summarization of data

Layer	Inner/outer	A hit rate MHz/sensor	M hit rate MHz/sensor	A hit density MHz/cm2	M hit density MHz/cm2	A Data rate Mbps/sensor	M Data rate Mbps/sensor	A Data rate Mbps/cm2	M Data rate Mbps/cm2
OldGeo DataRate = HitRate * 32bit / pixel * 3pixel / hit @(53%Gap)									
1	i	1.622	2.164	0.495	0.660	155.718	207.736	47.521	63.396
	o	1.150	1.790	0.351	0.546	110.407	171.799	33.694	52.429
2	i	0.074	0.201	0.022	0.061	7.074	19.281	2.159	5.884
	o	0.044	0.116	0.014	0.035	4.248	11.127	1.296	3.396
3	i	0.012	0.041	0.004	0.013	1.164	3.940	0.355	1.202
	o	0.009	0.029	0.003	0.009	0.842	2.777	0.257	0.848
NewGeo DataRate = HitRate * 32bit / pixel * ClusterSize @(53%Gap)									
1	\	1.983	2.451	0.496	0.613	493.018	652.018	123.255	163.004
2	\	0.378	0.842	0.090	0.200	70.927	116.668	16.887	27.778
3	\	0.098	0.196	0.023	0.047	18.845	47.790	4.487	11.379
4	\	0.044	0.153	0.010	0.035	9.144	51.128	2.078	11.620
5	\	0.015	0.108	0.004	0.033	3.363	33.700	1.026	10.284
6	\	0.010	0.070	0.003	0.021	1.920	14.796	0.586	4.515

No trigger and error window here.

A for average, M for maximum.

Occupancy



Layer	Maximum Occupancy@Pixel (e-5/BX)	Average Occupancy@Pixel (e-5/BX)	Occupancy @Sensor (%/BX)
1	2.266	1.813	67.813
2	0.505	0.336	19.031
3	0.189	0.091	5.717
4	0.175	0.041	2.678
5	0.191	0.020	0.966
6	0.117	0.014	0.676

@Pixel refers to the proportion of pixels that are fired on each sensor within each bunch crossing

@Sensor indicates the proportion of sensors that are fired on each layer within each bunch crossing

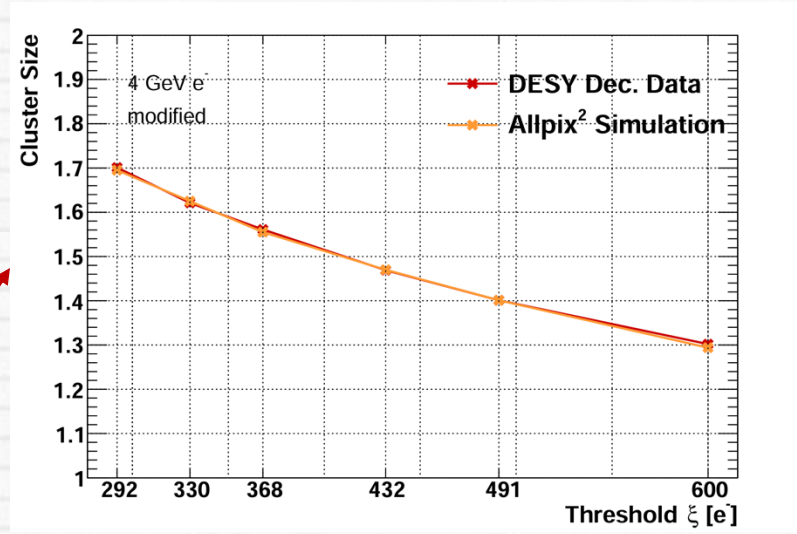
Weakness & Future Plan

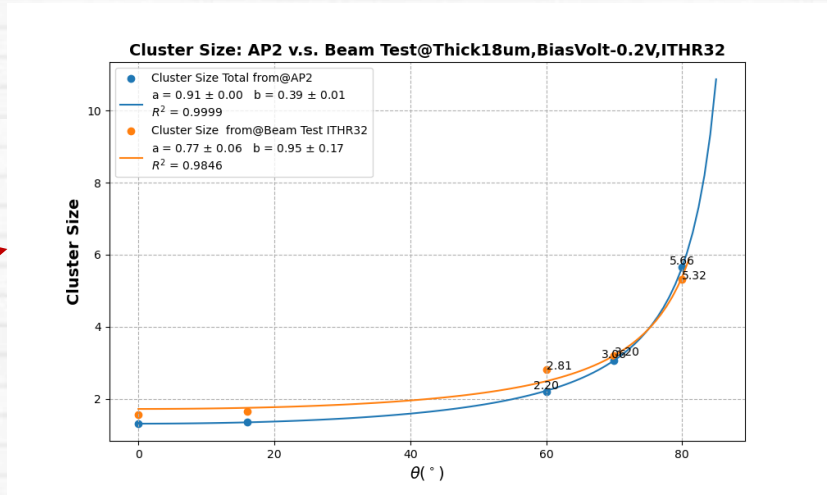
Weakness:

- Merging of every simulation step is primitive.
- The estimation of cluster size is based on an empirical model.
- Trigger and error window are not yet taken into consideration.
- ……

Future Plan:

- By incorporating the reconstruction process, we comprehensively analyze the particle trajectories within the sensor to obtain reliable hit data.
- Connect AllPix-2 with CEPCSW for digitization.
- ……





Thanks for Your Attention!